RESTORATION ECOLOGY

THE NEW FRONTIER

Second Edition

EDITED BY JELTE VAN ANDEL & JAMES ARONSON

WILEY-BLACKWELL

RESTORATION ECOLOGY

To
Heleen and *Arieke*
Thibaud and *Perrine*

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Edited by Jelte van Andel and James Aronson

with the assistance of
Christelle Fontaine and Bérengère Merlot

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Ongoing restoration along the Wemmershoek River in the Western Cape, South Africa. (Photographs: D.M. Richardson)

Top (1985). Invasive Australian wattles (*Acacia longifolia* and *A. mearnsii*) and cluster pine (*Pinus pinaster*), from the Mediterranean region, dominate the landscape.

Bottom (2011). Following clearing of invasive trees by the government-funded Working for Water Programme natural regeneration of native plants has helped bring the ecosystem to a healthy condition and water once again flows in the streams. Remaining non-native trees on the left are Casuarinas that serve as a windbreak for fruit orchards.

- “For this second edition of *Restoration Ecology: The New Frontier*, editors Jelte van Andel and James Aronson have organized a world-class group of authors to create the most comprehensive restoration ecology textbook currently available. I believe *Restoration Ecology: The New Frontier* is a substantial contribution to the science of restoration ecology and will contribute to our ability to create an improved future.”

  From the Foreword to this book by Professor Steven Whisenant, Texas A&M University and Chair of the Society for Ecological Restoration.

- “This newly revised and fully updated edition should be on the shelf of every restoration ecologist. Not a ‘how-to’ book, but a fine overview of many of the conceptual and interdisciplinary issues involved.”

  Truman Young, University of California at Davis

- The editors of Restoration Ecology provide a prompt and adequate response to the challenge of our era: to reconcile the link between humanity and nature. Jelte van Andel and James Aronson broaden their work to include New Frontiers and a global perspective in the second edition, supporting a paradigm shift in decision making which is unavoidable if we are to cope with the global environmental crisis. The reader is convinced that ecological restoration is vital to maintain biodiversity and their services, the basis of our life. This fundamental book will certainly contribute to the global effort of restoring 15% of degraded land by 2020, as expressed in the Aichi Biodiversity Targets. It offers clear concepts and practical knowledge at the level of biomes to train scientists and practitioners and to provide knowledge to bridge the gap in the science–policy interface. I recommend the book to use in restoration planning, for the training of students and in science communication.”

  Katalin Török, Centre for Ecological Research, Hungary and
  SER Europe Board member

CONTENTS

This book has a companion website www.wiley.com/go/vanandel/restorationecology with Figures and Tables from the book for downloading.

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FOREWORD

By some estimates, nearly two-thirds of all ecosystems have been degraded by human activities. This depletion of our global 'natural capital trust fund' makes it less likely we can sustain current levels of ecosystem services. Ecosystem degradation that diminishes biological diversity or alters nutrient and hydrologic processes has serious impacts that can no longer be ignored. Direct economic losses to agriculture, livestock production, forestry, and recreation are well-known consequences of ecosystem degradation. Less understood, yet equally important, are the implications for food security and poverty. Providing for future human populations, currently over seven billion and rising toward nine billion by 2050, will be increasingly difficult. You probably wouldn't be reading this if you weren't troubled by these trends and committed to improving our collective future.

The practice of ecological restoration is a proactive approach to addressing the real-world challenges of ecosystem degradation. Our ultimate goal is to understand ecosystem functioning and apply science-based practices that solve these significant environmental problems. It is increasingly clear that ecosystem degradation has social, economic, and biophysical causes that interact at multiple spatial and temporal scales. Thus, effective restoration strategies must address this complexity in ways that vary considerably with each unique set of circumstances. This has proven to be a significant and ongoing challenge for the evolving discipline of restoration ecology. Fortunately, I believe the book you hold in your hands will be a seminal contribution toward those lofty goals.

For this second edition of *Restoration Ecology: The New Frontier*, editors Jelte van Andel and James Aronson have organized a world-class group of authors to create the most comprehensive restoration ecology textbook currently available. Significantly, the book begins by developing a robust conceptual framework linking ecosystem damage to the primary causes of degradation and potential restoration strategies. Subsequent chapters provide numerous ecosystem-specific examples selected to illustrate and reinforce those concepts and provide a framework for future endeavors. I found these chapters to be both interesting as individual case studies and effective at illustrating the book's conceptual framework. The book concludes with discussions of uncertainties associated with climatic, evolutionary, and community processes and how to incorporate those ideas into sustainable restoration strategies. I believe *Restoration Ecology: The New Frontier* is a substantial contribution to the science of restoration ecology and will contribute to our ability to create an improved future.

Steven G. Whisenant
College Station, Texas
January 2012

Professor and Head of the Department
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PREFACE

At the turn of the twenty-first century, some 15 years ago, conservation biology and restoration ecology were clearly identified by some as vital 'hopes for the future' (Dobson *et al.* 1997). E.O. Wilson (1998) went further: given the current state of affairs, he said, a forward-looking, global society committed to a better future would devote much energy and resources, throughout this century, to restoration. But why, 'all of a sudden', do thoughtful scientists like Wilson, and many others, urge society to devote a century to ecological restoration?

Throughout human history, that is for the last hundred thousand years or so, people have explored and exploited natural resources to meet their needs for food, fresh water, timber, fibre, medicines and fuel. While recognizing that this has contributed to substantial gains in human well-being, over the millennia, the rapidly increasing 'ecological footprint' of humans, during the last two centuries in particular, has resulted in a substantial and largely irreversible loss in the diversity of life, the resilience of ecosystems and the quality of our own collective habitat on this Earth. Some say we are moving towards a precipice. Unquestionably, we have set off the first human-caused extinction crisis in the history of the planet; we have also set off climate change processes the consequences of which we cannot predict let alone control.

One hundred and ten years ago, we were one billion. Now the situation is radically different: we have a population of seven billion, adding another billion every 12 years or so, and about a fifth of humankind is consuming far more resources per capita than anyone but kings and queens had ever dreamt of before. Conclusion: we need a new *modus operandi* if we wish to move away from the precipice. We now have to work hard, and together, to 'restore towards the future', to borrow a phrase from the Society for Ecological Restoration (SER), which is the major international nongovernmental organization (NGO) in this field since 1987. We also need to shift paradigms and move towards sustainability. And justice. In short, towards a sustainable and desirable future for our children and grandchildren

By the last quarter of the twentieth century CE[1], many could see that traditional nature protection and management techniques, aimed at stopping further degradation of threatened ecosystems and landscapes, and preserving what was still more or less intact in set-asides or 'protected' areas, were no longer going to be enough. Whether the primary goal of conservationists was to safeguard perspectives for well-functioning, evolving 'nature', including biodiversity in all its forms, and to insure what is currently called the flow of ecosystem goods and services to people, restoration of degraded ecosystems was going to be necessary as well. An important trailblazer in this area was the late Anthony Bradshaw, who initiated research in the United Kingdom to learn how to reconstruct ecosystems on what he called derelict lands, left behind at the end after closure of mining sites (Bradshaw 1983).

Today, ecological restoration is a fast-growing and increasingly important component in the business, politics and applications of biodiversity conservation, ecosystem management, societal adaptation to climate change and legislated mitigation for ecological and environmental damage related to economic development. Restoration ecology as a science has come a long way too: as part of a dynamic feedback loop, the practice of ecological restoration calls for, and stimulates, ongoing development of concepts and theories, as well as short- and long-term field studies and experimentation providing scientific validation and underpinning for the practice. At the same time, it is providing much insight into the fundamental questions of biology and ecology at all levels of resolution, from landscapes and ecosystems to communities and populations. In other words, restoration ecology, at 30, is truly coming of age, in dozens of countries around the world. Scientists from different disciplines, along with engineers, technicians and other professionals, not to mention the thousands of amateurs and volunteers engaged in restoration, should all embrace the challenge to explore, test and, where appropriate, apply the theories, models and concepts coming from ecology, even though many of them were not conceived or developed in view of direct applications to restoration. Not all restoration practitioners may recognize the need for this, so let us explain why we say that.

In our approach towards restoration ecology, we consider a few elements essential. First of all, understanding of ecosystem structure and functioning is the central level of interest, even in cases where the reintegration of a disrupted landscape, or the rescue of biodiversity, is the main goal of a restoration project. For effective, long-lasting ecological restoration of an ecosystem, the first condition is to have as much knowledge as possible about its historic development, including human use and management, as well as misuse and mismanagement. The second condition is to analyse the causes of degradation and of current threats by applying scientific tools. The latter requires an interest both in fundamental ecological theories and models and in exploring their applicability. Techniques and approaches from the social sciences may be necessary as well, depending on the context. Last but not least, restoration ecology is intrinsically transdisciplinary, and has a huge role to play in the further development of both inter- and transdisciplinarity. Indeed, the reconstruction of earlier existing 'nature' or ecosystems, or the development of 'new nature', cannot be realized in isolation from societal and political will and impact. These elements are reflected in the structuring and the contents of this book.

In the first of four chapters in Part 1, which is intended to set the scene for all that follows, we briefly consider the historic situation of terrestrial and aquatic ecosystems in today's changing world. Next, we discuss key concepts in current restoration ecology, emphasizing the hot topics as seen from inter- and transdisciplinary perspectives. We have done our utmost to be consistent in the core concepts, and the terminology used throughout, and all general terms that appear in two or more chapters are defined in the detailed and original glossary provided near the back of the book. In the chapter texts, we have marked certain words in places where they can be useful to help the readers find their way to textbooks and scientific journals. All words and terms printed in italics appear in the index; terms in bold are defined in the glossary and included in the index.

In view of future requirements for the development of restoration ecology, the third, invited, chapter in Part 1 is devoted to implications for ecological restoration of climate change and other global changes, one of the most intriguing and complex problems we must cope with. And finally, in the last chapter of this part, planning and implementing successful restoration are discussed by two distinguished veterans in this field.

In the four interrelated chapters of Part 2, the basics of ecology and genetics are discussed in search of concepts and theories – at the levels of landscapes, ecosystems, communities and populations – that can or could be made applicable to ecological restoration in general, or some specific situations. Particular attention is paid to the problems and prospects related to the reinforcement and reintroduction of populations of animals or plants within a restoration context.

We then move on to Part 3, where the reader will find 11 chapters by invited sets of distinguished authors who discuss the problems and perspectives of ecological restoration as they have experienced them personally across a broad range of ecosystems and biomes. We here use the classic biome-by-biome approach to help readers quickly find the specific settings they are most interested in, and compare the barriers and options existing between biomes. These specialists and recognized experts in the science and the practice of ecological restoration provide a solid scientific background to evaluate the consequences of different human interventions and management measures aiming at restoration in a very wide range of biophysical and bioclimatic contexts. All the chapters in this part follow a similar approach, which should help students and other general readers get the most from them. In each of them, the authors discuss what we can learn from restoration successes and failures in the past.

In the fourth and final part of the book, the concepts and approaches mentioned in the first part are recalled, and the reader is invited to reflect upon the consequences, and help identify the perspectives, for ecological restoration in the coming years. How to cope with uncertainties, for example, is a key question. Particular attention is paid to evolutionary and community dynamics related to dramatic changes in the environmental conditions, and to coping with associated invasions of alien species. The ultimate goal of ecological restoration is to achieve sustainable, resilient and interconnected ecosystems, and socio-ecological systems, providing goods and services to humans and habitat and well-being for nonhuman creatures as well.

The present book is an enlarged, enhanced and updated edition of the first university-level textbook to have appeared on restoration ecology in any language (van Andel & Aronson 2006). While working on the updates of those chapters that appeared in the first edition of this book, six short years ago, we discovered how much new information has become available. Not only have new results from long-term field experiments become available, but also these results have given rise to new insights, and slowly shifting paradigms. The notion of 'restoring to the future' is a good example.

As before, the book is designed for senior undergraduate- and graduate-level courses in all disciplines related to fundamental and applied ecology, environmental studies, conservation and development. We think it will be useful especially in Europe, North America, Australia and New Zealand, but have in mind also students, researchers, teachers and others in the tropics and developing countries as well. It should provide a solid scientific background for managers and professionals involved in protected area, park or nature reserve management where restoration is being practised or contemplated, as well as practitioners of ecological restoration in governmental and nongovernmental organizations. Ecological restoration is one of the best bridges available to reconcile the seemingly opposing imperatives of nature conservation and economic development. As such, it constitutes one of the key components of the increasingly urgent search for sustainability — hence the use of 'New Frontier' in the title of the book. We hope that readers will find that this volume is helpful in their efforts to pave the way towards the future. Today's students, after all, are tomorrow's decision makers.

ACKNOWLEDGEMENTS

The editors are indebted to the team of enthusiastic chapter authors, all international experts in their fields, who bring to this book a huge amount of knowledge and expertise, while agreeing to respect a certain format and basic terminology. We are also very grateful to dozens of colleagues who reviewed manuscripts of chapters in this book, and who are acknowledged by the various authors. A special song of appreciation goes to Christelle Fontaine and Bérengère Merlot for their careful coordination and fine-tuning of all our editorial work. They contributed in particular through the verification and quality assessment for bibliographic references, figures, photos, and tables, and handled obtaining the reproduction permissions for the figures borrowed from other publications.

As for the first edition, in 2006, we dedicate this book to our children, those cherished and respected representatives of the upcoming generation who will inherit this beautiful, beleaguered and precious planet, and must shoulder the task of working for sustainability, environmental ethics and social justice in the twenty-first century CE.

Jelte van Andel and *James Aronson*
Groningen and Montpellier, January 2012

NOTE

1. The abbreviation CE refers to Common Era, a secular alternative to AD, while BCE stands for Before Common Era, substituting for BC. We will use these abbreviations throughout the book.

Part 1

Setting the Scene

Restoration Ecology: The New Frontier, Second Edition. Edited by Jelte van Andel, James Aronson.

EDITORS' INTRODUCTION

Rather than being just concerned and conservative about remains of 'wild nature', ecological restoration requires a dynamic, adaptive approach to problem solving and resource management, especially in this era of rapid and irreversible change in climate, land use and species assemblages. Indeed, evolutionary and environmental dynamics, such as invasions of species outside their recent biographical ranges, and anthropogenic climate change, can no longer be denied or ignored, as was often the case when ecological restoration was associated solely with nature conservation concerns. However, as we think about potential future developments in ecological restoration, we must respect the historic roots of our human societies, and the relationship between them and nonhuman nature as well. Evolution of species has been a natural phenomenon throughout the history of life on Earth, but the direction and speed for some species have been strongly influenced by human activities, such as plant and animal breeding, and also indirectly affected by our growing impact on global, regional and local environments. Similarly, climate change has been a natural phenomenon since the very beginning of the Earth's existence, but the recent rate of change is recognized by all experts as being largely due to human impact. This is one of the main reasons why humanity must accept responsibility for its actions, and include nature management in the decision-making process of planning towards a sustainable and desirable future – especially as we climb from the current 7 billion people to an estimated 9–10 billion in the next 25 years.

Not only does nature alter in response to changes in environmental conditions, but also human societies change and adapt to new conditions. Wilderness, earlier considered as areas to be exploited for human well-being, is nowadays valued as near-natural ecosystems to be cherished and protected. Similarly, what was earlier considered as 'wastelands' may now be called seminatural ecosystems; if financing is provided, even derelict and devastated post-mining areas may effectively be revegetated, rehabilitated and 'recycled' into the mainstream of society. However, for ecological restoration to be successful, a firm agreement is required between all the stakeholders. Opportunities have to be valued in terms of scientific validation, societal needs and available budgets for execution and monitoring.

We start our book by giving a brief overview of changing points of view on nature and on the goals of nature management, along with changes in the human society (Chapter 1). In brief, this implies a change from human dependence on nature towards nature's dependence on human management. In Chapter 2, we present some of the key concepts in the field of restoration ecology where for example we explain how to distinguish between the reintegration of disrupted and dysfunctional landscapes, the restoration of degraded ecosystems, and the rescue of biodiversity through the reinforcement or reintroduction of species populations. We also discuss such concepts as stability, the functional role of biodiversity, reference systems and how stocks of natural capital allow the flow of ecosystem services. However, we note that despite recent progress huge uncertainties and unknowns remain in our field.

In Chapter 3, our colleague Richard Hobbs pays explicit attention to this problem, helping the reader focus on the challenge of coping with ongoing changes in climate even as we set about the restoration of degraded ecosystems in the context of highly modified landscapes. Indeed, an intriguing and important question is to what extent historical knowledge and perspective can continue to be applicable if we are restoring now 'towards the future', as we put it in the preface. Finally, David Tongway and John Ludwig describe an approach to landscape-scale restoration that emphasizes the need for understanding how ecosystem processes are affected by disturbances, causing landscapes to be dysfunctional (Chapter 4). This knowledge can then be used by practitioners to set achievable goals, and to design and implement restoration technologies to achieve their goals.

In summary, this first part of our book sets the scene for all that follows. Rather than giving a complete overview, we aim at highlighting topics that we consider to be necessary elements for the reader who will here discover the rapidly growing, and evolving, field of restoration ecology; we hope it will give you an appetite to carry on reading the book and at least some of the references cited and, above all, to start thinking about concepts and strategies for differing biophysical and sociocultural contexts where ecological restoration is needed.

Chapter 1

GETTING STARTED

Jelte van Andel and *James Aronson*

Restoration Ecology: The New Frontier, Second Edition. Edited by Jelte van Andel, James Aronson.

1.1 INTRODUCTION

Increasing and unrelenting human impact on the biosphere – in particular since the industrial revolution began in the late eighteenth century – has brought us to the threshold of what Paul Crutzen dubbed the 'Anthropocene Era', that is an unprecedented geological era in which humans dominate all ecosystems and the global environment as a whole. However, the widespread recognition of the need to regulate the human 'footprint' dates back only a few decades, in most parts of the world. Pioneer nature conservation organizations began to be formed over a century ago, it is true, in western and central Europe in particular – including the German Nature and Biodiversity Conservation Union, founded in 1899, and the Dutch organization known as *Natuurmonumenten* that was founded by an elementary school teacher in Amsterdam in 1905. Today, there are literally thousands of conservation NGOs around the world, and gradually, over the past 50 years, they have found increasing support from the public and the scientific community. Although started as recently as the 1960s, 'in response to the devastation of our natural habitats', the network of Wildlife Trusts in the United Kingdom now has more than 800 000 members. This is just one example among many, and ecological restoration – under many different names – is gaining an increasing share of attention in conservation activities all around the world, and in international treaties as well.

In this introductory chapter, we start using the terminology related to the subject without defining the terms; the definitions will be given and discussed in the next chapter. Throughout the book we draw the reader's attention to the Glossary in this book by marking terms in bold.

Restoration ecology is the field of study and experimentation that provides the scientific background and underpinnings for practical **ecological restoration**, rooted in the early developments and visionary work of a few individuals and programmes in the nineteenth and twentieth centuries. It has grown to a respectable 'size' and volume only in the last few decades, since Bradshaw's (1983) pioneering work, but as mentioned already, is now gaining momentum and attention as never before. Restoration ecology has also begun to command much more attention from scientists in the last 25–30 years, especially since the Society for Ecological Restoration has got underway in the late 1980s. Twelve years ago, ecologist Truman Young suggested that 'restoration ecology is the future of conservation biology' (Young 2000). By that he surely meant that in today's crowded, much-transformed world, conservation – in the sense of preservation or setting-aside – will not be adequate to meet the goals of conservation – and sustainability. Instead, restoration of damage will be required on both scores. In terms of the sciences, at any rate, a clear convergence between the three fields is taking place, conservation biology, restoration ecology and the overarching, inter- and transdisciplinary field of **sustainability science** that is barely a decade old. Why include the latter in this introductory chapter? Because ecological restoration does not only aim at the repair of degenerated ecosystems, including their structure and functioning and their biodiversity. For ecological restoration to be effective, we must consider not only the biophysical context, but also the socio-economic and political matrix in which a restoration project must be planned, financed and carried out. That is why there is a clear need for a broader interdisciplinarity, and **transdisciplinarity** as well, which means forging interprofessional partnerships and coalitions, as well as good communication and indeed collaboration with nonprofessional stakeholders and neighbours. Jackson *et al.* (1995) portrayed ecological restoration as having four main components to consider – ecological, social, cultural and economic (see Figure 1.1). In the last few years, however, it is also becoming clear that political and legislative components are needed as well (Aronson 2010) and will also be an important part of restoration in coming years.

Ecological restoration aims at the safeguarding and the repair of what is commonly called 'nature' (i.e. **ecosystems** and **biodiversity**) and what ecological

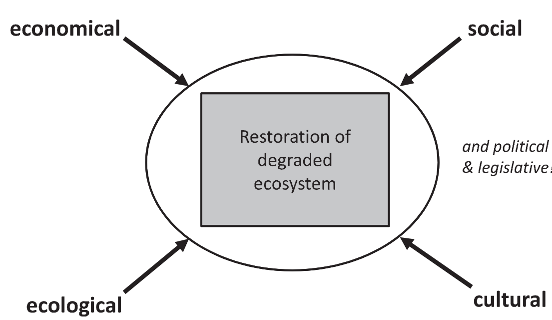

Figure 1.1 Five main components of ecological restoration. Modified from Aronson (2010).

economists, and a growing number of ecologists, call humanity's stock of **natural capital** (i.e. renewable and nonrenewable resources from 'nature') that assure the flow of **ecosystem goods and services** to society (Aronson *et al*. 2007a). Thus, many motivations and justifications for ecological restoration exist (see Clewell & Aronson 2006, and Chapter 2), yet a financial – and perhaps also a social or political – cost is inevitably involved. Increasingly, it is obvious – at least to us – that all societies everywhere should be devoting resources to this activity to insure and enhance the supply of ecosystem services as well. However, what may seem like a clear gain for some, can be perceived as a loss or waste of resources for others. Trade-offs, negotiation and, above all, good communication are a *sine qua non* in this realm of human endeavour that require both ecological and environmental as well as socio-economic and even political criteria for monitoring and evaluation (Blignaut *et al*. 2007; Aronson 2010).

Needless to say, points of view in most situations will differ among **stakeholders**, and they will also change over time, in any heterogeneous society, and even among specialized scientists. To illustrate this, let us consider the concept of steady states and disturbance, a key notion in all discussions of conservation, management and restoration of ecosystems.

1.2 VIEWS ON STEADY STATES AND DISTURBANCE

Disturbance, though it may sound negative, is basically a neutral term in science. The term is widely used in **ecology**, and we will also use it in this book, but the neutral term 'transformation' is often a better choice for indicating a change of a complex system from one state to another one. What we call a **disturbance factor** causes a change or transformation in an ecosystem's steady state, in terms of its standing biomass, productivity or biodiversity, which may be followed by either *recovery* to the former state (through **resilience** or **resistance**) or a change to another state, following the crossing of a so-called **threshold of irreversibility** (see Figure 1.2); then the system is disturbed. In the latter case, the system may shift to another steady state, or not; in the ecological literature, this new state is referred to as an **alternative stable state**.

Depending on your point of view, State C, the alternative steady state, can be a gain or improvement, or else a loss or example of degradation. For example, if a

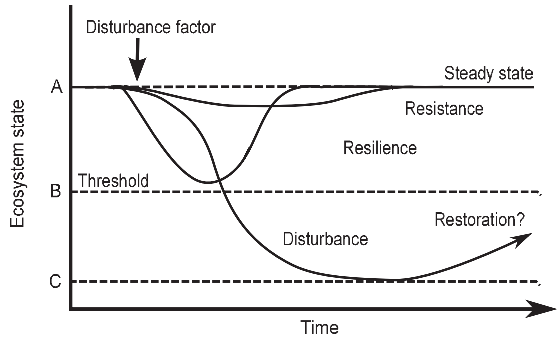

Figure 1.2 Model of three types of system response to a disturbance factor: resistance, resilience and disturbance. State A is the starting or 'initial' steady state, State C is a new, alternative steady state. As long as the system state does not pass a 'threshold of irreversibility' (State B), the system remains stable. Restoration of the ecosystem from State C towards the starting state A is affected by hysteresis and by the nature and number of the threshold(s) it has crossed.

farmer clears a piece of woodland and then cultivates the land, he or she will naturally consider the change as a gain. Yet, from the point of view of a bird watcher, or local authority in charge of nature conservation, such a transformation may be considered as a loss of **habitat** for birds, or a **degradation** of the woodland ecosystem at the landscape scale. Similarly, local communities dependent on woodlands for various services (for example watershed protection and outdoor recreation) will consider it as negatively impacting their welfare and well-being. Thus, especially if the farmer eventually abandons production, for reasons of changing markets for example, there may be a good argument that ecological restoration should be attempted, in order to restore the woodland that once was there. However, the farmer may instead seek other crops or land uses that raise income to his or her family or corporation. In Chapter 2, we will return to the concept of **disturbance**, and the related one of **stability**. Here we will consider points of view on 'nature' as related to the qualification of 'disturbance'.

1.3 VIEWS ON NATURE AND NATURE CONSERVATION

Just as views on what constitutes a disturbance differ, the same is true for notions of 'nature', 'nature conservation' and 'ecological restoration', and points of view may even change over time. In large parts of northern and central Europe and indeed the entire northern hemisphere, the **forests** and **woodlands** that developed after the last Ice Age ended, approximately 11 000 years ago, have repeatedly been exploited or even clear-cut for timber, and the lands they formerly occupied cleared and burnt to make way for agricultural production systems. Though this disturbance, or transformation, from forest or woodland to farmland and pasture sometimes resulted in heavy soil erosion, it was generally considered as a gain for the farmers, and for the entire society. From the Middle Ages up to the beginning of the twentieth century, the prevailing land use in Europe was low-intensity farming, resulting in agro-ecosystems such as species-rich meadows and open **heathlands**, currently known as seminatural ecosystems. In Figure 1.3, we illustrate this notion schematically, in the broader context of the range of anthropogenic disturbances to ecosystems and the alternative states or conditions presented already in Figure 1.2.

After the introduction of artificial fertilizers in the early twentieth century, the application of which enables intensive production of food, these less intensively used farmlands were no longer considered as a gain; instead they were called 'non-use lands' or even 'wastelands' that should, logically, be 'reclaimed' for production. Large-scale fertilizer application resulted in a new change of the ecosystem state, from low-intensity farmlands to increasingly high-input, high-production systems. Again, this change was appreciated by most farmers, but not by all members of society, especially those concerned with **sustainability**. The high level of nutrient supply to the soil resulted in a steep decline in **biodiversity**, not only in the cultivated areas, but also in adjacent landscapes. Nature conservationists, who had taken initiatives to establish formal nongovernmental institutions to counteract the ongoing process of what they considered as degradation of the environment, were gradually supported by scientists from universities and research institutions who conducted detailed studies and provided quantitative data on the impacts. Increasingly, points of view

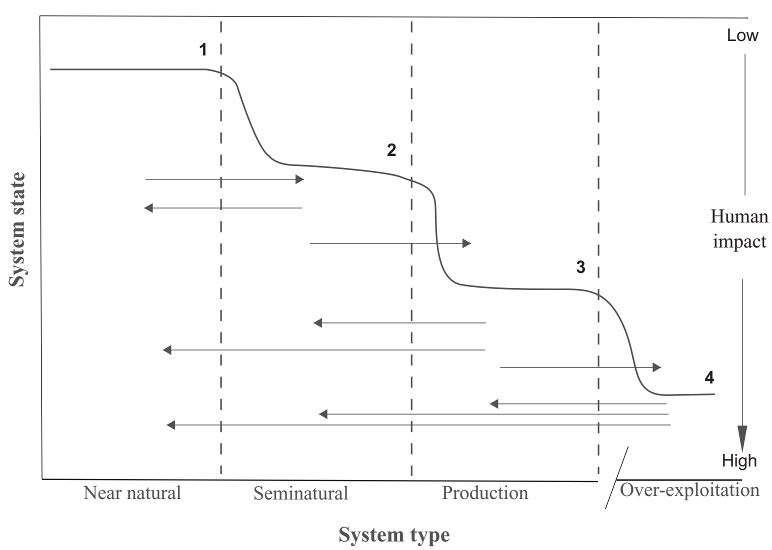

Figure 1.3 Schematic representation of common transformations of ecosystems. Arrows from left to right indicate anthropogenic disturbances; arrows from right to left indicate options for ecological restoration or rehabilitation, or, alternatively, reclamation to some type of sustainable system. Note that the route to recovery or restoration of an ecosystem after prolonged disturbance and profound transformation often takes much longer than, and differs from, the initial route of degradation. This discrepancy is known as hysteresis. It is important that restorationists and restoration scientists not forget or underestimate this factor of unpredictability, which generally increases in correlation to the degree of human impact.

about the aims of nature conservation became under debate, mainly related to the degree of desired or allowed human **intervention**. In 1945, for example, the Royal Dutch Society for Natural History (KNNV) organized a conference to identify and agree on the choices for aims of nature conservation and management (van der Windt 1995). The dilemmas were discussed among landscape architects, nature conservationists and managers, and scientists. A choice was made for **seminatural ecosystems and landscapes** as a primary goal of nature conservation and management. The most important conclusion was that the principle of including human interventions in nature was no longer questioned, thus leaving room for different options. Currently, it is common use to recognize three archetypes of 'nature', dependent on the degree of naturalness (see Swart *et al*. 2001): (1) **wilderness**, or self-regulating near-natural ecosystems, (2) **Arcadian or seminatural ecosystems**, based on a long history of extensive human interference, and (3) intensively managed **production systems**. The intensity of human impact may be strong or moderate or even zero, depending on the view of nature applied to different sites, ranging from production systems to some kind of wilderness. In Figure 1.3 we used these three categories, and added the notion of *over-exploitation* as a fourth step in the disturbance of a system to an alternative state; the latter state can no longer be considered part of 'nature'. In the next section we will present views on various options for the repair of different disturbed states.

1.4 VIEWS ON RESTORATION

The focus of nature conservation has been on the preservation of near-natural and seminatural ecosystems through preventing them from being degraded. Ecological restoration has much broader perspectives, aiming at the repair of damage, now including the ecological restoration or rehabilitation of production and exploitation systems (see Figure 1.3). And again, there are often difficult choices to be made, even when the general goal of ecological restoration has been agreed upon. Indeed, in most situations a broad range of targets can be distinguished, from spontaneous or assisted recovery to the former state, to a state that one could call a halfway condition with respect to the former state. Currently, different options for restoration are recognized: (1) **near-natural restoration**, aiming at almost non-assisted natural recovery, (2) **ecological restoration**, that is, the return to some historic **reference system**, representing pre-disturbance conditions, be it natural or seminatural, (3) **ecological rehabilitation**, that is, the improvement of **ecosystem functions** without necessarily a return to pre-disturbance conditions, and (4) **reclamation**, that is, conversion of heavily degraded land such as post-mining areas to a productive condition.

However, new problems continually pop up. Nature management, as agreed upon, and the restoration of abandoned production systems, may result in successes and failures. Sometimes the return to past ecosystem types simply can not be achieved by re-applying the former management measures. Irreversible environmental conditions, for example due to severe drainage of peat soil or high soil-nutrient loads, could prevent or severely retard a return to the past, and this raises the need to consider other options. Currently in the field of restoration ecology, it is generally accepted that a return to past ecosystems, indeed a return to the past in general is, strictly speaking, not possible; history can not be repeated. This implies that the notion of **reference systems** should no longer be conceived of in a narrow fashion, or restricted to an idealized situation of the past. Instead, it can be conceived, and then utilized, in many different ways. A reference system may change over time and may in fact be developed as a series of successive reference states or systems (Figure 1.4).

There is also a need to recognize uncertainties involved in restoration, and the reality that many ecosystems today are in fact **emerging ecosystems** (see Part 4), since the world has changed so radically, from a biologist's point of view, and will continue to change, as a result of climate change, land use change, biological invasions and so on. In Chapter 3, we will also encounter the notion of **novel ecosystems** that have entirely altered from historical ranges. There the main aim of restoration might be to ensure the maintenance or optimization of the flow of material ecosystem goods and services with less concern for cultural services or biodiversity or any spiritual or cultural ties with the past. Several chapters in Part 3 will deal with this theme, and we will reflect on the different options available in the three concluding chapters of Part 4. Now, at the beginning of our journey through this book, we would like to emphasize that ecologists' primary job is to provide as much information as possible to make predictions, and effective applications in ecological restoration projects, based on historical, analytical, and experimental

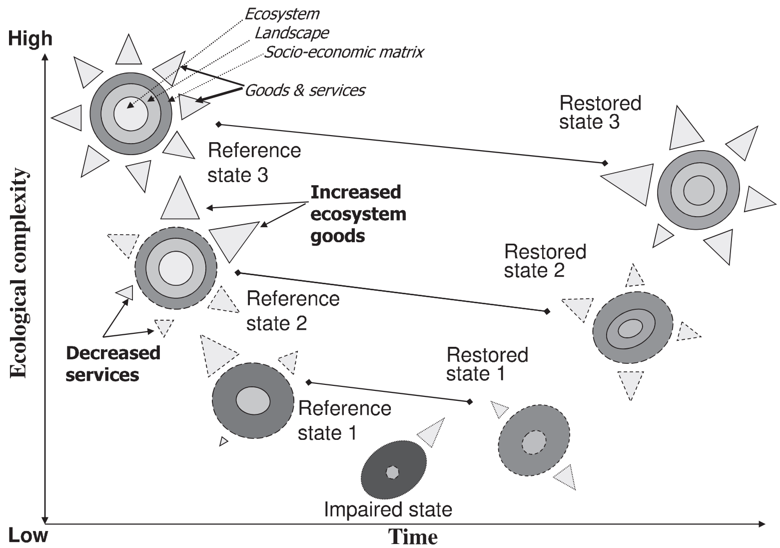

Figure 1.4 Sequential references in ecological restoration. Dashed lines represent degraded conditions as compared to an intact, undisturbed system. The inner circles in each 'sun' on the figure represent the ecosystem. The outer concentric circles of each 'sun' represent the landscape (biophysical matrix of the ecosystem), and the socio-economic matrix, in which the ecosystem is embedded. The triangular 'rays' of each 'sun' represent various goods and services that flow from the 'natural capital' that is an intact ecosystem with its native biodiversity. From Clewell and Aronson (2007); reproduced with permission from Island Press.

knowledge of patterns and processes of 'nature' (i.e. ecosystems and biodiversity at all relevant scales and levels of organization). We recall that restoration ecology is essentially a branch of applied ecology (see Freckleton *et al*. 2005) – that is, ecological research that informs management practice to be used by society as a whole.

In this first chapter, we have indicated the starting place for our project. As mentioned, several of the concepts that we introduced here will be elaborated on in Chapter 2 as part of a set of what we consider the unifying concepts for restoration ecology, indispensable for appreciating the chapters that will follow.

Chapter 2

UNIFYING CONCEPTS

Jelte van Andel, Ab P. Grootjans and *James Aronson*

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2.1 INTRODUCTION

Restoration ecology is an applied natural science that lies at the intersection with the social sciences, but can also help us leap from that broad platform into the realm of transdisciplinary science and problem solving, which we will discuss below. Restoration ecology is thus truly a 'new frontier', as first noted by one of the most notable and prolific pioneers in the field, in the introduction to the book he edited (Cairns 1988), which was one of the very first books to appear on this topic.

In this book, we focus on the ecological foundations of restoration ecology. We feel strongly that restoration efforts must aim to restore entire ecosystems, and not just focus on parts of them, or other derivative goals. Increasingly, we hear and read about the need to 'restore' **biodiversity**, or **ecosystem services**, but these goals are ultimately vain if we do not succeed in restoring living, dynamic ecosystems, and figuring out how to help them be self-sustaining. It is difficult or impossible to 'restore' or rather **reintroduce** species populations in a given site, without 'restoring' the abiotic environment necessary for the persistence and reproduction of those species, including the networks of interactions with many other species that occur in a well-functioning **ecosystem**. Conversely, **biotic communities** strongly influence the abiotic environment, and without a full complement of native species, autogenic or self-sustaining ecosystems – the ultimate goal of ecological restoration – will not be attained (MacMahon & Holl 2001). Thus, we endorse the definition given in the *SER Primer for Ecological Restoration* we cited already, namely, that **ecological restoration** is 'the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed' (SER 2004).

Note the emphasis in that definition on the idea of assisting the recovery of an ecosystem, and not just a species. The definition explicitly assumes that something has been lost, or gone wrong at the level of a system, and, secondly, it implies that we can and should try to understand how ecosystems respond to interventions of all sorts, including efforts to help them recover. Ecological restoration is interventionist and systems-oriented by nature, as opposed to traditional conservation, that was about reducing human pressure or 'keeping our hands off' certain areas of land or wetland set aside for protection of one or an assembly of species. It is hands on, and is, by definition, applied at the level of whole ecosystems.

The corresponding field of science called restoration ecology can take various approaches to the task of providing knowledge that will help put ecosystem recovery in motion. New theories and syntheses, predictive models and the testing of hypotheses through experiments and careful monitoring and evaluation of ongoing projects are the primary means to achieve that end. Additionally, outreach and collaboration with people from other academic disciplines, in both the natural sciences (e.g. conservation biology and landscape ecology) and the social sciences, including economics, as well with nonscientists and professionals, is essential. That will require engaging in the 'entire restoration process' (Cairns & Heckman 1996). In this chapter, then, we focus on the major unifying concepts relevant to both fundamental and applied ecology, but start with the notions of inter- and transdisciplinarity.

2.2 INTER- AND TRANSDISCIPLINARITY

Restoration ecology draws knowledge, ideas and data from disciplines as diverse as landscape ecology (including geomorphology and hydrology), community ecology along with soil and water physics, and chemistry at the ecosystem scale, as well as physiology and genetics at the level of organisms and populations. But as mentioned, to address and engage the 'entire restoration process', we must incorporate the socio-economic sciences (e.g. Mascia *et al.* 2003). This implies cross- or *interdisciplinarity*, which is what happens when concepts, models, methods and findings of different scientific disciplines are merged together and integrated to address an idea, or to solve a societal problem (Schoot Uiterkamp & Vlek 2007).

Scientists need to cross traditional lines and work together in the essential arena of environmental amelioration and management. The word 'transversal' – which means cross-cutting – is rarely used in English as an adjective, and yet it beautifully describes what is needed: not just a summing of skills, but also an actual breaking of new ground, thanks to original or 'lateral' thinking, resulting from a new juxtaposition and combination of approaches. In order to help **stakeholders**, and society as a whole, in the urgent task of